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Renewable Building Thermal Insulation – Oil Palm Fibre

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ABSTRACT

The increasing negative effect on the environment necessitates the search for viable biodegradable renewable materials for use as building thermal insulation. This study investigates the potential for oil palm fibre as an environmentally friendly building thermal insulation. Thermal conductivity measurements at mean test temperatures of 20°C, 25°C and 30°C were conducted on oil palm fibre specimens within the density range 20 kg/m^3 to 120 kg/m^3 in accordance with ASTM C518. Results indicated that oil palm fibre exhibited the characteristic hooked shape variation of thermal conductivity with density and the minimum thermal conductivity occurred at 100 kg/m^3. Thermal conductivity increased with mean test temperature. The optimum thermal conductivity value within the 20°C to 30°C mean temperature range averaged 0.05675 W/m.K. From the experimental data an empirical correlation varying with density and temperature was derived. The correlation predicted the thermal conductivity of oil palm fibre within 5% of the experimental value.

Keywords: *building insulation, oil palm fibre, biodegradable insulation, renewable insulation*

I. INTRODUCTION

With the advancement in technology better and more sophisticated man-made materials are being produced for building thermal insulation. However, many of these synthetic products do not break down naturally when disposed in landfills. The degradation can be hundreds of years in some cases as the effect of water, air and soil have little impact on the materials. The increasing negative effect on the environment necessitates the search for viable biodegradable renewable materials for use as building thermal insulation [1].

Renewable fibrous thermal insulation made from trees, plants or animals with the ability to regenerate itself and biodegrade easily when disposed as waste can significantly reduce negative environmental impact [2]. If managed effectively renewable biodegradable building thermal insulation can have a net reduction in CO_2 emissions over the life cycle and be continuously replenished. A cheap, reliable and abundant supply of biodegradable fibrous materials can be obtained as waste by-products from many commercial agricultural processing industries [3]. Materials such as coconut fibre, sugarcane fibre, cotton, wheat straw, oil palm fibre and others consist of lignocelluloses fibres and are promising alternatives for use as biodegradable, renewable, environmentally friendly building thermal insulation [2, 3]. This study investigates the viability of using oil palm fibre as building thermal insulation.

II. MATERIAL

The term biodegradable in this study refers to material that occurs naturally in nature and when disposed off will decompose without causing any adverse effects on the environment [4]. In this context by-product from the oil palm agricultural processing industry was considered. The waste material from the oil palm processing industry showed a high degree of fibrous content. When shredded the resulting oil palm fibre exhibited physical properties of fibres with a mean diameter of 0.250 mm with a range between 0.104 mm to 0.502 mm and a standard deviation of 9.04 x 10^{-2}. The length of the fibers was between 30mm to 100mm. When arranged in a slab-like form the minimum density of the oil palm fibre without settling is 20 kg/m^3. The thermal characteristics of the Oil palm fibre arranged as a thermal insulation batt at varying density was investigated for possible use as building thermal insulation [5, 6].

Thermal Conductivity Test Specimen

Thermal conductivity measurements were conducted on 51 mm thick, 254 mm square test specimens (Figure 1). The specimens were contained in a polystyrene specimen holder constructed from 25.4 mm thick polystyrene strips, 51 mm high (Figure 2).

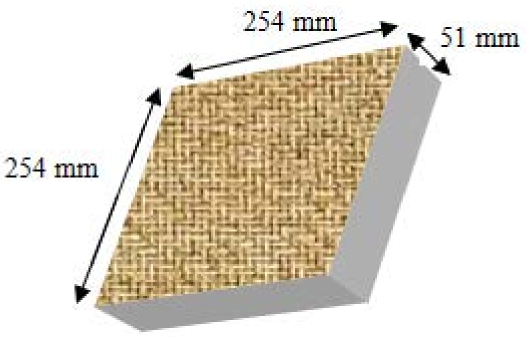

Figure 1: Schematic of Oil Palm Fibre Test Specimen

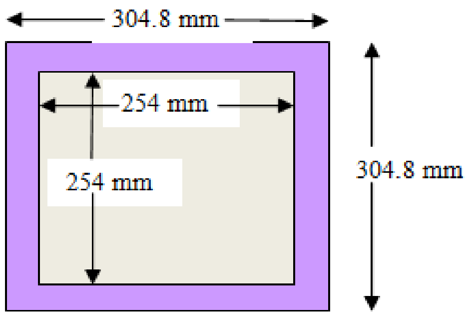

Figure 2: Schematic of Polystyrene Specimen Holder

Oil palm fibre samples were randomly selected from stock pile that was allowed to acclimatize to laboratory conditions. The fibres were packed into the specimen holder forming a slab-like 51 mm thick specimen. The density of the test specimen was changed by varying the mass of the fibre within the fixed size specimen holder. The fibre strands were generally perpendicular to the direction of heat flow across the test specimen when the fibre was randomly arranged in the slab-like batt.

Thermal Conductivity Measurement

The thermal insulating properties of oil palm fibre was measured in accordance with ASTM C518 where the effective thermal conductivity, □, was measured under steady -state one-dimensional test conditions with heat flow upwards [7]. The test equipment used constant temperature plate 305 mm x 305 mm with a centrally located 102 mm x 102 mm heat flux transducers. The test equipment provided measurements with ±0.2% repeatability and ±0.5% reproducibility within the range 0.005 W/m.K to 0.35 W/m.K [7].

The minimum specimen test density was determined by the lowest possible density for which the material existed without any appreciable settling under gravity. The clamping force between the constant temperature plates of the test equipment determined the upper test density limit. The minimum test density without settling for the oil palm fibre batt, 51mm thick, was 20 kg/m^3. The maximum test density used was 120 kg/m^3 as the clamping force between the constant temperature plates of the test equipment was not able to compress specimens of higher density to the required 51 mm thickness.

Table 1: Experimentally Determined λ for Oil Palm fibre

Density (kg/m^3)	Thermal Conductivity λ (W/m.K)		
	20^{o}C mean temp.	25^{o}C mean temp.	30^{o}C mean Temp
20	0.09167	0.09466	0.09824
30	0.07576	0.07777	0.07809
40	0.06754	0.06801	0.06950
50	0.05961	0.06115	0.06316
60	0.05987	0.06006	0.06041
70	0.05730	0.05829	0.05997
80	0.05699	0.05690	0.05813
90	0.05607	0.05733	0.05796
100	0.05550	0.05690	0.05784
110	0.05580	0.05733	0.05800
120	0.05642	0.05782	0.05890

III. ANALYSIS OF RESULTS

The experimental results for oil palm fibre indicated the general trend associated with loose-fill thermal insulation [4, 5]. That is, as density increases from the minimum density value, thermal conductivity, λ, decreases to a minimum and then increases. Therefore, the λ variation with density, ρ, should satisfy the general empirical relationship associated with this characteristic behaviour for materials of this nature as given in equation (1) [6, 8].

$$\lambda = a + b\rho + c/\rho \qquad (1)$$

Using the Method of Least Squares, the experimental data for oil palm fibre at mean test temperatures of 20^{o}C, 25^{o}C and 30^{o}C, respectively, was fitted in the form of Equation

(1) and the empirical constants were determined. The resulting best fit equations are as follows:

Oil palm Fibre at 20 °C mean test temperature;

$$\lambda_{20,\text{ best fit}} = 0.0346 + (1.0027 \times 10^{-4})\rho + 1.1127/\rho \qquad (2)$$

Oil Palm Fibre at 25 °C mean test temperature;

$$\lambda_{25,\text{ best fit}} = 0.0329 + (1.1660 \times 10^{-4})\rho + 1.1992/\rho \qquad (3)$$

Oil Palm Fibre at 30°C mean test temperature;

$$\lambda_{30,\text{ best fit}} = 0.0309 + (1.4146 \times 10^{-4})\rho + 1.2915/\rho \qquad (4)$$

Another characteristic feature of lose-fill insulation is a linear increase of λ with mean test temperature and can be represented in the for [7].

$$\omega(T) = d + e.T \qquad (5)$$

where $\omega(T)$ is an expression for temperature dependence, d and e are constants, and T is the temperature. In general, the experimental results for oil palm showed an increasing λ with mean temperature which is consistent with thermal conductivity for materials of this nature. In order to determine λ variation with mean test temperature, the respective coefficients of a, b, and c, from the best fit equations for oil palm fibre at 20°C, 25°C and 30°C were fitted to a relationship in the general form of equation (5)

This resulted in general empirical relationships for determining λ in terms of temperature and specimen density for oil palm fibre.

$$\lambda = (0.0424 - 3.7 \times 10^{-4}T) + (1.6468 \times 10^{-5} + 4.1190 \times 10^{-6}T)\rho + (0.7541 + 0.0179T)/\rho \qquad (6)$$

Using the general empirical relationship, equation (6), specific empirical equations for the thermal conductivity of oil palm fibre within the density range 20 kg.m^3 to 120 kg/m^3 were determined for mean temperatures of 20°C, 25°C and 30°C and are given in equations (7 – 9).

Empirical equation for effective thermal conductivity of Oil palm Fibre at 20 °C mean test temperature;

$$\lambda_{20,\text{ empirical}} = 0.0350 + (9.8848 \times 10^{-5})\rho + 1.1121/\rho \qquad (7)$$

Empirical equation for effective thermal conductivity of Oil palm Fibre at 25 °C mean test temperature;

$$\lambda_{25,\text{ empirical}} = 0.0332 + (1.1944 \times 10^{-4})\rho + 1.2016/\rho \qquad (8)$$

Empirical equation for effective thermal conductivity of Oil palm Fibre at 30 °C mean test temperature;

$$\lambda_{30,\text{ empirical}} = 0.0313 + (1.4004 \times 10^{-4})\rho + 1.2911/\rho \qquad (9)$$

To determine the accuracy of the respective equations determine the effective thermal conductivity the λ was calculated at mean test temperatures of 20°C, 25°C and 30°C, from both the general empirical relationship and the best fit equation and compared with the experimental results. This data is shown in tables 2-4.

Table 2: Experimentally Determined, Best Fit Equation and Empirical Equation λ for Oil Palm fibre at 20°C

Density (Kg/m^3)	Experimentally Determined Thermal Conductivity $\lambda_{20,\text{ exp.}}$(W/m.K)	Best Fit Equation (2) Thermal Conductivity $\lambda_{20,\text{best fit.}}$ (W/m.K)	% deviation of Best Fit λ from experimental λ	Empirical Equation (9) Thermal Conductivity $\lambda_{20,\text{ empirical}}$ (W/m.K)	% deviation of Empirical λ from experimental λ
20	0.09167	0.09224	-0.62	0.09258	-0.99
30	0.07576	0.07470	1.40	0.07504	0.95
40	0.06754	0.06643	1.64	0.06676	1.15
50	0.05961	0.06187	-3.79	0.06218	-4.31
60	0.05987	0.05916	0.07	0.05947	0.67
70	0.05730	0.05751	-0.37	0.05781	-0.89
80	0.05699	0.05653	0.81	0.05681	0.32
90	0.05607	0.05599	0.14	0.05625	-0.32
100	0.05550	0.05575	0.45	0.05600	-0.90
110	0.05580	0.05575	0.09	0.05598	-0.32
120	0.05642	0.05590	0.92	0.05613	0.51

Table 3: Experimentally Determined, Best Fit Equation and Empirical Equation λ for Oil Palm fibre at 25°C

Density (Kg/m^3)	Experimentally Determined Thermal Conductivity $\lambda_{25, exp.}$(W/m.K)	Best Fit Equation (2) Thermal Conductivity $\lambda_{25,best\ fit.}$ (W/m.K)	% deviation of Best Fit λ from experimental λ	Empirical Equation (9) Thermal Conductivity $\lambda_{25, empirical}$ (W/m.K)	% deviation of Empirical λ from experimental λ
20	0.09466	0.09519	-0.56	0.09567	-1.07
30	0.07777	0.07637	1.80	0.07684	1.19
40	0.06801	0.06754	0.69	0.06802	-0.01
50	0.06115	0.06271	-2.55	0.06320	-3.35
60	0.06006	0.05988	0.30	0.06039	-0.55
70	0.05829	0.05819	0.17	0.05873	-0.75
80	0.05690	0.05721	-0.54	0.05777	-1.53
90	0.05733	0.05672	1.06	0.05730	0.05
100	0.05690	0.05655	0.62	0.05716	-0.46
110	0.05733	0.05663	1.22	0.05726	0.12
120	0.05782	0.05689	1.61	0.05755	0.47

Table 4: Experimentally Determined, Best Fit Equation and Empirical Equation λ for Oil Palm fibre at 30°C

Density (Kg/m^3)	Experimentally Determined Thermal Conductivity $\lambda_{30, exp.}$(W/m.K)	Best Fit Equation (2) Thermal Conductivity $\lambda_{30,best\ fit.}$ (W/m.K)	% deviation of Best Fit λ from experimental λ	Empirical Equation (9) Thermal Conductivity $\lambda_{30, empirical}$ (W/m.K)	% deviation of Empirical λ from experimental λ
20	0.09824	0.09830	-0.06	0.09866	-0.43
30	0.07809	0.07819	-0.13	0.07854	-0.58
40	0.06950	0.06885	0.94	0.06918	0.46
50	0.06316	0.06380	-1.01	0.06412	-1.52
60	0.06041	0.06091	-0.83	0.06122	-1.34
70	0.05997	0.05925	1.20	0.05955	0.70
80	0.05813	0.05836	-0.39	0.05864	-0.88
90	0.05796	0.05798	-0.03	0.05825	-0.05
100	0.05784	0.05796	-0.21	0.05822	-0.66
110	0.05800	0.05820	-0.34	0.05844	-0.76
120	0.05890	0.05864	0.44	0.05886	0.07

IV. DISCUSSION

Experimental data at various mean test temperatures show the thermal conductivity variation with density for oil palm fibre followed the characteristic hooked shape associated with loose-fill fibrous insulation [9, 10, 11]. The λ variation with density at mean test temperatures of 20°C, 25°C and 30°C showed the minimum λ value of 0.05550 W/m.K, 0.05690 W/m.K and 0.05784 W/m.K, respectively, at 100 kg/m^3. This indicated that the optimum density for oil palm fibre occurred approximately at a density of 100 kg/m^3. Also, λ showed an increase with mean test temperature which is consistent with the behaviour of loose-fill thermal insulation [12].

The general empirical equation developed from the experimental data predicted the effective thermal conductivity at mean temperatures of 20°C, 25°C and 30°C within 4.31%, 3.35% and 1.52%, respectively. Also, the best fit line showed respective variation within 3.79%, 2.55% and 1.01% from the experimental values. The λ calculated from the equations for the best fit line and the general empirical equation at mean test temperatures of 20°C, 25°C and 30°C all indicated the minimum λ for oil palm fibre occurred at approximately 100 kg/m^3. The empirical relationships for the λ variation with temperature and density for oil palm fibre indicated behaviour consistent with loose-fill insulating materials. The empirical correlation derived is capable of predicting the λ within 5% accuracy for oil palm fibre over the test range investigated.

The minimum λ for oil palm fibre ranged between 0.05550 W/m.K to 0.05784 W/m.K over the mean temperature ranges 20°C to 30°C. These λ values are within the range for use as loose fill thermal building insulation and as a naturally occurring materials have the advantage of being environmentally friendly (biodegradable). However, consideration has to be given to the flammability of the material and the high density at which λ is minimum. Also, susceptibility to insect attack and fungal growth over long time periods need to be investigated.

V. CONCLUSIONS

- Oil palm showed acceptable λ values for use as building thermal insulation.
- The optimum λ value within the 20°C to 30°C mean temperature range averaged 0.05675 W/m.K.
- The λ increased with temperature within the test range. This behaviour is consistent with loose fill insulating material.
- Oil palm fibre exhibited the characteristic hooked shape graph of thermal conductivity with density. This behaviour is consistent with loose fill insulating material.
- The material has the advantage of being environmentally friendly (biodegradable).

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